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Landslides, degradation and erosion in Hong Kong

M. R. PEART
Department of Geography and Geology, University of Hong Kong, Hong Kong

Abstract Little attention has been devoted to assessing the impact of landslides upon land degradation and denudation in Hong Kong. However, some estimates of at-a-point erosion are presented. The landslides which occurred in the Lam Tsuen valley in May 1989 are used to illustrate how they can influence sediment production. The use of instrumented basins and observations of the size of the failure site as a means of evaluating sediment production by landslides are discussed. The complications to these methods posed by the sampling and sediment delivery problems are presented. Where subsequent erosion of landslide sites by fluvial action generates sediment, monitoring of sediment in rivers may be the only way of quantifying their impact upon erosion. The need to consider scale in instrumented basin studies is discussed. Sediment quality is introduced as a further aspect of the linkage between landslides and sediment production that is worthy of investigation.

INTRODUCTION

A recent geotechnical survey of Hong Kong, the location of which is shown in Fig. 1, indicates that a substantial part of its land area evidences slope instability. Styles & Hansen (1989) report that well defined landslides (those greater than 1 ha and suitable for mapping at a scale of 1:20 000) affect 1.2% or 1335 ha of the land mass. However, most of this area (1233 ha) is associated with coastal instability. A further 20.4% of the Territory evidences general instability. This includes areas where, for example, large numbers of landslides occur which are too small to be mapped individually at the adopted scale. Styles & Hansen (1989) summarize the instability problem in Hong Kong as follows "slope instability of some form or other is relatively common within the Territory ...".

Other researchers have noted the frequency of mass movement in Hong Kong. For example, Brand (1985) reports that on average several hundred slope failures occur each year, but he goes on to caution that many of these failures are small. He also states that a significant landslide event, which may be regarded as one in which a large number of failures occur, might be expected to occur in the Colony once every two years. The majority of mass movement slope failures occur, according to Brand (1985), in man-made features, or, are triggered by such features which include cut slopes. Severe landslide events were occurring in the Territory as long ago as 1889 according

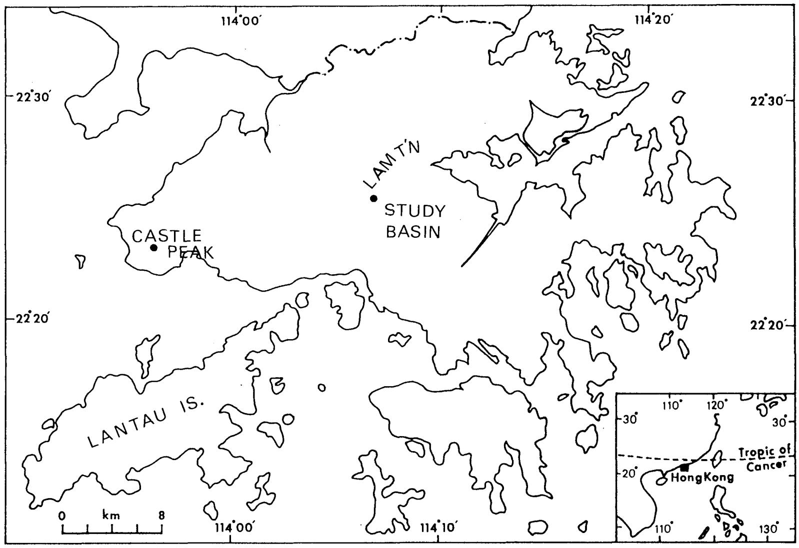

Fig. 1 Location of Hong Kong and the study area.

to Brand (1985). So (1978) and Ruxton (1980) offer evidence of the variety of types of mass movement slope failure which can occur in Hong Kong. Earth flows, mud flows, debris avalanches, shallow washouts, and deep seated slips involving rotational shearing and slumping are all mentioned by So (1978).

It can be concluded that Hong Kong suffers appreciably from landslides. A considerable body of information has been gathered regarding origin and causes (e.g. Brand, 1985; Brand *et al.*, 1984; Lumb. 1975) and much effort has been placed upon assessment, control and prevention (e.g. GCO, 1984; Brand, 1988). In contrast little information has been obtained on the geomorphic effect of landslides especially in terms of sediment production in watersheds. This is surprising given the importance of reservoirs, catchwaters and rivers in providing water for Hong Kong. This paper reviews the evidence for sediment production from landslides and examines the problems in assessing the impact of landslides upon fluvial sediment production in the Territory. Some suggestions are also made as to other aspects of landslide and sediment production, such as sediment quality, which might profitably be considered in Hong Kong and elsewhere.

LANDSLIDES AND AT-A-POINT EROSION

There is some information available on at-a-point erosion caused by mass movement slope failure in Hong Kong. For example, Lam (1974) indicates that most of the slips observed in his three small study basins were not more than 2 m deep. Brand *et al.* (1984) report that most slip failures are shallow with the thickness of the failed zone being less than 3 m. Ruxton (1980) cites Allen

& Stephens (1971) as observing that 21 slips in southwest Lantau Island were about 1 m in depth. Malone & Shelton (1982) state that systematic recording of landslides began in Hong Kong in 1978. They report that the most common failures were landslides of residual or weathered rock in cuttings. Of the 97 failures recorded in the period 1978-1980 only six were greater than 15 m high. In May 1989 typhoon Brenda caused several landslips in the Lam Tsuen valley. Of the 10 slips visited the average depth was less than 3 m. One of the failures had a depth of over 4.5 m.

These depths of erosion or surface lowering can be compared to slope erosion rates monitored by Lam (1974) for other erosion processes, mainly wash. He reports mean gross slope erosion rates for badland surfaces of 1.4 cm and 2.167 cm respectively for 13 and 15 month observation periods.

LANDSLIDES AND SEDIMENT PRODUCTION

In contrast to the availability of frequency and depth of failure data for landslips, landslides and debris flows in Hong Kong, little information is available on their role in sediment production in river basins. Only one study, that of Lam (1974), has examined quantitatively sediment production in drainage basins in the Territory. His investigation was carried out over a 15 month period in 1971/1972 in three small basins in the Tai Lam Chung region. In these catchments with a total area of 79 ha Lam (1974) observed 16 shallow landslip scars, two of which occurred during the study period. He suggests that because of the small number and size of the slips they contribute little to the total sediment discharge of the streams. He also identifies two ways in which landslides can affect sediment production. There are directly, when displaced material in delivered or washed into the stream, and indirectly, when the weathered material of the scars and deposited sediment is eroded by subsequent rainfall events. Lam (1974) reports that part of the debris in the slips may be arrested lower down the slope.

The landslides and debris flows which occurred in the Lam Tsuen valley in May 1989, consequent upon heavy rainfall associated with Typhoon Brenda, provide more evidence of how rapid mass movement slope failure may influence sediment production. Data obtained by air photo interpretation and field surveys reveals that out of the approximately 31 failures, the failed material was deposited in or adjacent to stream channels in 13 cases. However, for most of these slides some material was also deposited on the hillslope, sometimes only a metre or so from the site of the failure. In respect of the remaining 18 failures, the displaced sediment did not reach the stream channel. However, some of these failures have contributed sediment indirectly to the drainage system for there is evidence that subsequent fluvial action has eroded both the scar and deposited material and delivered this to the drainage system. Indeed even those failures which delivered sediment to the drainage system showed evidence of subsequent fluvial action providing additional material.

Two major problems exist in quantifying the contribution of landslips to the total volume of sediment exported from drainage basins in Hong Kong. The first can be classified as a sampling problem, both in space and time. As stated previously, in May 1989 typhoon Brenda resulted in very high rainfall over Hong Kong. For example, on 20 and 21 May, 526 mm and 425.7 mm respectively were recorded at Shek Kong and the Royal Observatory. In the area of the Lam Tsuen valley, where a new instrumented basin had been installed in March 1989, many landslips occurred. However, no failure occurred within the study basin itself and although the results obtained reflect sediment production in an extreme event they do not illustrate the role of mass movement.

The spatial sampling problem is further illustrated by the event of 10 and 11 September, 1990. At this time the largest historically recorded natural slope failure ever observed in Hong Kong occurred on the eastern slope of Castle Peak (see Fig. 1). Langford & Hadley (1990) estimate that up to 35 000 m^3 of material was deposited between 20 and 110 MPD (Mean Principal Datum) by the debris flow. It is believed (Langford & Hadley, 1990) that the debris flow was caused by rainfall of around 200 mm which occurred on the 10 and 11 September, especially the 140 mm which fell between 0100 and 0700 on 11 September. Similar amounts of rainfall occurred in other areas of the Territory and yet the only major slope failure was at Castle Peak. No major landslip or slide occurred in the Lam Tsuen region near the instrumented basin. Although there is considerable information in Hong Kong as to the causes of landslides (e.g. Brand *et al.*, 1984; Lumb, 1975) and the fact that this knowledge can be applied to develop a model to predict landslide susceptibility in particular regions or areas (e.g. Harris, 1984) it is not possible to predict exactly where failure will occur.

Given the difficulty of predicting precisely where landslides will occur in Hong Kong it is difficult to select a basin and be confident of monitoring a major failure. This is especially problematic if the investigation is to be short term in duration. For although some researchers indicate that major landslide generating events occur on average every two years (e.g. Brand, 1985) this means that short duration studies associated with, for example, a Masters or Doctoral thesis, have a high probability of not experiencing major failures. The study basin on the slopes of Kwun Yum Shan has been operational for three wet seasons and only in the first of these has a high incidence of slope failure occurred.

If sediment monitoring in streams is to be used to quantify the effects of mass movement two other considerations are important. The scale of the basin has implications for the results. A landslide occurring in a small first or second order basin is likely to have a different impact than one occurring in a large basin where the impact may be lessened by other tributaries. Furthermore, given that investigations such as those undertaken by Rawat (1987) and Ichim & Radoane (1987) indicate that sediment delivery declines with stream order, scale will complicate the delivery problem. In addition it will be necessary to calibrate the basin such that the normal response can be established and used

There also remains the problem of length of record. Wolman & Miller (1960) identified the need to consider magnitude and frequency in evaluating geomorphic effectiveness. This consideration is particularly important in determining the contribution made by landslides to sediment production. Hong Kong is fortunate in having a good air-photo coverage such that determining frequency of failure for many areas is not difficult. In some areas good secondary sources of data exist (e.g. Brand *et al.*, 1984). However, some areas, including the Lam Tsuen valley have a much more restricted air-photo coverage and a lack of other sources of evidence.

An alternative method of evaluating sediment input to the fluvial system from landslides, which does not involve instrumenting a basin, involves measuring the volume of material removed from the site of failure. Determination of the depth, width and length of the failure can give an estimate of the volume of material produced. However, this method can be difficult to adopt in some cases because of the sediment delivery problem. This is illustrated by the 31 landslips and slides which occurred near the study basin in the Lam Tsuen valley in May 1989. Debris from a number of these slides reached stream channels. However, as stated previously much of the material remains in the channels and some of the sediment remains in storage on the slope, never having reached the vicinity of the channel. This was also the case for major failure on the slopes of Castle Peak which occurred in September 1990. The sediment delivery problem makes this method difficult to use, especially in the failures like those in Hong Kong where considerable storage occurs, both on the slopes and in the channel. Moreover, where sediment is produced by rilling and or wash erosion of the failure scars and deposited material, monitoring sediment production in streams at the basin outlet may be the only practical method of detecting and quantifying this source.

Where more detailed information is available of landslide occurrence through time and on site characteristics such as unit weight of soil, friction angle, slope gradient and soil depth more sophisticated models such as that developed by Benda & Zhang (1990) can be used to evaluate the impact of landslides upon sediment yield.

LANDSLIDES AND SEDIMENT QUALITY

Although some studies (e.g. Dietrich & Dunne, 1978; Lehre, 1981) have quantified the contribution of mass movement to sediment production, less attention has been given to their impact upon sediment quality. Given that in Hong Kong landslides generally involve removal of all weathered material from A to C/D soil horizons, it might be expected that the sediment delivered to the stream will be different to that produced by rill and wash erosion.

In the Lam Tsuen valley some 10 landslide scars were sampled at various depths to characterize the eroded material produced by rapid mass movement failures. These samples were compared to A horizon material obtained at the failures. These samples were compared to A horizon material obtained at the same locations which would characterize the material eroded by rilling and wash action. Table 1 presents the organic carbon, nitrogen and phosphorus concentrations along with loss on ignition values for the samples. It can be seen that the landslide scar material has very different levels of organic carbon, total nitrogen and total phosphorus, and the loss-on-ignition values indicate a much lower organic matter content in comparison to the A horizon material. Although allowance must be made for selective erosion and contrasting sediment delivery, Table 1 suggests that there is potential for the sediment produced by landslides to be very different to that provided by splash, rill and wash erosion.

Table 1 Landslide scar and soil characteristics.

Sample source	Loss on ignition (%)	Nitrogen (%)	Organic carbon (%)	Phosphorus (%)
Surface Soil	7.5	0.184	2.3	0.0041[a]
Landslide Scar	5.3	0.096	0.37	0.0035[a]

[a]Mean values based upon 10 bulk samples.

This may in part be confirmed by observations made on suspended sediment samples collected in the small study basin and bottom sediments obtained from the Lam Tsuen River. A number of bottom sediment samples were collected in the Lam Tsuen River just downstream from cuts associated with a road improvement scheme. This material may be considered similar to that provided to the stream by landslides for it consists predominantly of B, C and D horizon material. Analysis of the < 2 mm fraction of these samples provides mean values of 2.96%, 0.46%, 0.09% and 0.007% respectively for loss-on-ignition and organic carbon, nitrogen and phosphorus content. These are similar to those of the landslip scar and provide evidence, albeit indirect, that rapid mass movement failures, which deliver abundant weathered material, will provide sediment with characteristics that are different to that where only surficial soil materials are eroded. For the instrumented basin suspended sediment samples collected on Whatman GFC filter papers have been ashed at 400°C to determine organic matter content. For the 1989/1990 and 1990/1991 water years some 33 and 106 samples respectively were ashed giving mean loss-on-ignition values of 26.7% and 33% respectively. These levels are dissimilar to those found in either the soil, the landslide scar or the bottom sediment samples from the Lam Tsuen River. The results may indicate that the selective nature of the erosion and transport processes causes differentiation of the suspended matter in comparison to source material and bottom sediments. It may, therefore, be difficult to use source material analysis of landslides debris to predict its impact upon sediment quality.

CONCLUSION

Evidence has been presented that landslides in Hong Kong may result in at-a-point erosion depths ranging from under 1 m to over 15 m. However, little evidence is available on the role of landslides in sediment production by streams and rivers. Observations made on landslides in Hong Kong reveal that they may contribute sediment both directly and indirectly to the fluvial system. Examples from Hong Kong are used to illustrate the sampling problem, which has both spatial and temporal components, and the sediment delivery problem in quantifying sediment production from landslides. Comments are made on the use of instrumented basins and landslide dimension analysis as means of determining their role in sediment production by streams. Sediment quality has been introduced as a topic worthy of further consideration with respect of landslides and sedimentation. It has been suggested that landslides will deliver sediment with differing properties to the drainage network in comparison to situations in which only the surface layers of soil are eroded.

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